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Towards a low-carbon energy sector in Denmark

Per Sieverts Nielsen
Technical University of Denmark

Abstract: *Our modern society is significantly challenged in trying to stop emission of greenhouse gases, which are threatening to create significant changes to the earth's climate. This paper focus on the aim of transforming the Danish energy sector from a fossil fuel based system to a system based on renewable energy sources. The Danish Parliament has in the last three to four decades had a long term vision of transforming the old energy sector towards using variable renewable energy sources. The recent long term goal is to be independent of fossil fuels in 2050. The paper looks at the Danish energy policies and discusses how the necessary transition is working along with or against global mega trends. Most recently a similar vision to the Danish vision of becoming carbon neutral in 2050 has been mentioned by the European Commission (EC). Fortunately, the Danish government appears to be aligned with many global mega trends, which will help Denmark achieving the transition to become independent of fossil fuels in 2050.*

Index Terms: *Energy policy, Energy transition, Sustainable energy, 100% RE*

I. INTRODUCTION

The current global trend in emission of greenhouse gases from the energy sector is still pointing up. This is despite the political debate on threatening climate change and international efforts to reduce emission of greenhouse gases through international agreements most recently the Paris Agreement [1]. However, the thread of climate change is overwhelming and the recent reports for the International Panel of Climate Change (IPCC) illustrates how much CO2 emissions have to be reduced to avoid irreversible climate change. Meeting the Paris Agreement will still increase emissions and lead to a warming of 3 °C by 2100. Limiting warming below or close to 1.5 °C would require a decrease of net emissions by 45% by 2030 and reach net zero by 2050. Even just for limiting global warming to below 2 °C, CO2 emissions should decline by 25% by 2030 and by 100% by 2075 [2].

To be fair to the current political environment, the task is massive and the technical as well as organizational and political tools at hand may in many cases not be suitable. The tools, solutions, energy services, energy policies will have to be very different and the way the energy sector operates has to change. The current stakeholder setup may therefore also have to change, which is obviously a thread to the current stakeholders. The problem we are facing appears to be obvious and the solutions for the problem also appear obvious. However, the energy system as we know it, where the vast majority of emission come from fossil fuels, has been built on freely and cheaply available fossil fuels. The new system will be different.

What is required is a transition to a system based on renewable energy sources, which will require significant changes to the way the system is currently operating. It will mean changing the system from production-follows-demand thinking to a demand-follows-production thinking in countries where the new supply system will be based on variable renewable energy resources (VRE) such as wind and solar. In other words, we will need to use energy when the wind is blowing and the sun is shining. This new system will have to be integrated across end-use sectors and energy sources and be supported by flexibility in the system, based on digital solutions, virtual storage and physical storage solution. This change of energy system thinking is very significant and many aspects of how the new system is going to operate is not yet clear.

In the IEA review of the Danish energy sector [3] a categorization of energy sector development towards a 100% RE energy sector is described in six phases. The idea is to describe the challenges and what need to be done in general terms when a country approaches the 100% VRE status. In the IEA analysis Denmark is currently placed at phase four: "VRE generation covers nearly 100% of generation

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at given times; system stability becomes a concern", and IEA suggests that Denmark is now going into phase five: "VRE generation exceeds demand on a regular basis. At this stage, in the absence of additional outlets for consumption (e.g. increased demand, exports, or storage), large-scale curtailment could limit further deployment". The role of flexibility is not highlighted in the description of phase five in the report, but IEA do dedicate one chapter in the report to addressing the need and the potential for flexibility in the whole system, including at the demand side.

II. METHODOLOGY

The analysis in this paper is based on data of the current state of the Danish energy sector and the Danish energy policies, including the most recent Energy Agreement 2020-2030 [3]-[4]. Thereafter the sector and policy will be analyzed and discussed in consideration of megatrends. There is no one definition of what a megatrend is and the author has not seen any study where the energy sector development has been related to megatrends. The definition here is based on identifying mostly technical but also some socio-economic trends, which are happening in our modern society, whether we realize it or not. The reason for using mega trends for the analysis here is to help a discussion on whether we can achieve a 50% RE in 2030 in Denmark and even a 70% RE target, which was recently presented by the new government. It is obvious that it makes a big difference to a successful outcome of our policies whether we are working along with or working against megatrends.

We may not know why we are going in a certain direction, as a society, because so many aspects are having an impact on our society and our society is obviously very complex. The aim here is to try to understand some of the trends relevant for the energy sector and then use the knowledge to help understand why we are moving in a certain direction and why we are doing what we are doing. The analysis should help us decide what to do and what not to do. We should certainly avoid doing things, which are going against the mega trends if we can identify other options, which will work better because they work with the megatrends. We cannot change things, which are moving against megatrends. I define megatrends to be trends at the global scale, which it is impossible to change with the policy tools we have available in a democratic society.

III. DATA COLLECTION

In the following, the trends in the Danish energy sector over the last decades will be presented. Firstly, the focus is on the technical system to give a background to the Danish energy sector and secondly the focus is on the political initiatives. Understanding the Danish energy sector helps to understand the environment in which the political decisions are taken. Following the presentation of the Danish energy sector and energy policies, I will evaluate and discuss the alignment with megatrends on mostly the technical aspects of the Danish energy sector.

A. The Danish energy sector

The energy sector in modern societies varies, but fundamentally, they are based on a power grid, which delivers services to the commercial, industrial and residential sectors in the form of providing power for electric appliances, and power for heating and cooling. The commercial/industrial sector will typically take up one third of energy consumption and the residential sector one-third. The transportation sector will typically take up the last third. If the split is on type of end-use sectors, the building sector will use one third, whereas the commercial/industrial sector and the transportation will also use one third each. Although this paints a very generic picture of the energy sectors in modern societies, the energy sector in different countries is different when we dig into the details.

I will here focus on three aspects, which are very significant for the Danish energy sector. The heating sector and its use of district heating, the power sector and its transition into use of VRE and thirdly the transportation sector, which is fossil fuel based.

Heating: Denmark is geographically in the colder climate in the northern hemisphere so heating houses is necessary. This is the case for both residential and commercial buildings. However, what is special in Denmark is that almost half of heating is provided with district heating. District heating is a network of pipes dug in the ground, which transmits hot water from a heat production unit to the end-user typically buildings. These district heating networks have been built over the last 50 years and the networks are still being expanding. A detailed introduction to the Danish energy sector can be found

in [3].

Buildings: Across Denmark new buildings are being build every year, typically at 1% increase per year. The new buildings have to follow the most recent building code, which is updated regularly. The building code has become increasing strict over the years with regards to requirement for energy efficiency. Some commercial building may use building certification schemes where the German DGNB is the most popular in Denmark. However, the majority of housing stock in Denmark is still build either before the building codes were introduced or before the first oil crises when the focus on energy efficient buildings emerged. Energy savings in the building sector has been very important in the last decades because it takes up a major part of total energy consumption in Denmark. However, there are many problems in actually achieving the promised savings potential. It works well for new building where the energy efficient solution are integrated in the building design. Whereas it is more difficult to install the energy saving solution in the old housing stock. The most popular solutions are employing thicker insulation in the walls and roofs and replacing the windows. It is however, difficult to know if the promised energy savings have been achieved without actual monitoring. In some cases, the residents are able to maintain a comfortable indoor temperature after the renovation, which they were not before. This is good from a comfort point of view, but may not have reduced the energy consumption and therefore not reduced the CO2 emissions.

District heating is a very convenient solution for heating buildings because the heat sources are flexible. Originally most of hot water in the district heating system came from fossil fuel based system. Many of these fuels have been replaced with other energy sources, predominant biomass. But the hot water may also come from solar thermal, heat pumps, geothermal or surplus heat from the industry. Fortunately there is now a strong focus on diversifying the heat supply to the district heating network and many interesting new technologies are tested around the country.

Transportation: The transport sector has continuously been kept on the sideline with regard to energy planning. Energy consumption is more difficult to address here than power in the electricity grid and hot water in the district heating networks. Why is it so difficult to make the changes in the transportation sector? The fossil fuels are very convenient fuels for the vehicles. The fuels are cheap and the combustion engine is a cheap solution, and the stakeholders are strong. There have been very little attempts to compete with the internal combustion engines. Public transportation therefore has been the competitive alternative and in particular larger cities have widespread public transportation services. A popular alternative in Denmark to cycle. Copenhagen is in particular famous for a large part of the commuters is using a bicycle. Electrification is also happening in the transportation area. The public transport becomes electrified, train, busses, ferries, electric cars, electric bicycles and electric scooters. There are many new technologies introduced including the electric cars and that has the potential to be a significant game changer for the Danish energy system. With an electric car fleet, also comes a fleet of electric batteries, but its potential role is still unknown territory. The previous government did not specifically support the sale of electric cars and we are still waiting for specific new policies from the new government.

Electricity consumption: The energy sector will change and become more and more electric. It will mainly been driven by the production of electricity from an increasing number of wind turbines. Although solar PV is still more expensive than wind power the cost for producing electricity from solar PV has dropped during the last decade. When we reach a high penetration of wind power and solar power the challenge is to use the electricity when it is produced that means when the wind is blowing and the sun is shining. The connection between the electricity grid and the transportation sector and the heating sector is therefore very important: This is where the big potential for a more flexible use of electricity is imminent. Our electric appliances are made to work when we flick the switch on at the wall. By themselves they have very little flexibility. Using power from wind to run flexible heat pumps is a good solution for both the electricity and the heating sector.

B. VRE in the Danish energy sector

Denmark has had a target of being 100% independent of fossil fuels by 2050. This has meant 55% in 2030 in the recent energy agreement [4] and as listed in the top of Table 1. Table 1 shows the major parts of the energy agreement and they will be discussed later. However, in the recent government agreement of summer 2019 the target has increased to 70% by 2030 without the details of the plan available yet.

Table I: Initiatives in the energy agreement 2020-2030 based [4].

Initiatives – area	Description
New target for RE by 2030	55% of energy consumption should be covered by RE in 2030. With this agreement Denmark should have 55% RE in the whole energy sector and 100% green electricity in 2030.
Off shore wind	Three off shore wind turbine parks will be built with a total capacity of at least 2.400 MW before year 2030. The wind turbine parks are expected to be significantly cheaper than previous parks.
Tender for RE technologies	The parties will set up a fund to tender 0.5 B euros. To tender different energy technologies such as on-shore wind turbines and solar PV. These technologies will have to compete to deliver electricity at the cheapest price.
Biogas	The parties will set up a fund at 0.5 bill euros for further expansion of the production of biogas. A part of this is targeted biogas from organic farms.
Energy Savings in the industry	There will be 0.15 B euros annually in the period 2021-2024 for grants to target energy savings programs in the industry.
Reduction of tariffs on electricity	Reduction in tariffs on electricity and electric heating for 0.25 B euros in 2025. The tariffs on electric heating will be halved by 2021
Modernising District heating	The parties agree to work for a modern district heating sector, where the district heating companies can choose fuels and in the longer run, consumers will be free to choose to be connected to the district heating system.
Fuels choice in District heating	A fund is targeted for helping the district heating sector in overcoming previous support for being available for electricity production, and to promote use of surplus or waste heat and export of Danish energy technologies.
Fund for green transportation	There will be established a fund for green transport of nearly 0.1 B euros in 2020-2024, which should promote green mobility and transport.
Phasing out coal	The parties agree to phase out coal in the Danish electricity production in

	2030.
R&D	Energy and climate research will be promoted with the target of more than 0.1 B euros per year in 2024.

This is obviously a bigger challenge. This article will focus on potential solutions and whether they are supported by megatrends. The big questions is whether we can actually make a complete transition of the energy system from a system where production-follows-demand to a system where demand-follows-production. How do we change to make demand follow production? On a windy day with >12 m/s the wind power production exceeds demand. In other words more than 100% of the power is produced by the wind turbines. The surplus is exported to Norway or Sweden. On a no-wind cloudy day our RE production will go lower than 10%... and on no-wind nights it will go to zero. So how can we then make demand follow production – if there is no production? At present the power will then come from the thermal power production plants it it will be imported from Norway or Sweden. The alternative is based on integration, flexibility and storage. But are we then able to integrate that much – to be that flexible?

The 100% RE target is very difficult to achieve when it is not build on the large scale RE sources, such as hydropower. The large scale hydropower plants works well with old way the energy sector was operated. With large scale hydropower it is possible to still have an RE system where supply follows demand. But in the Danish case this is not possible, because Denmark is flat and we therefore we do not have hydropower available. The Danish system is connected to Norway and Sweden where hydropower is available, so these work as backup for the Danish energy sector currently when the wind is not blowing. However, although this works well technically, it is not a good financial model for Denmark, because when we have oversupply of wind power the price of power goes down, and may even become negative so we pay the Norway and Sweden to use our power for free. Contrary, when we want the power back when the wind is not blowing, the power is very expensive. A further increase in wind power production in Denmark is only to going to increase this discrepancy if we don't change focus towards end-use consumption and flexibility.

IV. MEGATREND ANALYSIS

In the following the energy policy initiatives in the energy agreement is analyzed in a megatrend perspective. The analysis is summed up in Table II evaluating pros and cons.

Economy: The Danish economy: Denmark is a rich country. The Danish economy is following the pattern of northern European countries with Germany as the main trading partner. The future development of the Danish economy is not likely to change from the current path. The Danish economy is diverse, with a stable growth. The Danish economy is not dependent or exposed to the performance of a single economic sector or exploitation of resources. Denmark has oil resources in the North Sea, which is discussed later.

Economy: Shift of economic power towards Asia: The global economy is seen to be shifting towards Asia with growing strength of the Asian economies compared to the western economics. This can be seen as a megatrend. The shift of economic power towards Asia is due to development of the Asian economies. The need for doing something in Western Europe is getting even more important. Some Asian countries install RE technologies and both Danish VRE and EE technologies are demanded. Despite this there doesn't appear to be any direct economic megatrend thread towards the Danish economy.

Economy: Oil and gas reserves in the North Sea: Denmark has oil and gas reserves in the North Sea. These have been extracted over the last three decades but the extraction has reached its peak and over the last decade the extraction rate has decreased. Previously Denmark had a large export of oil and gas, but today the extraction is only able to cover internal use. The decline in exploitation is not a surprise and has been expected from the start of the process. The lack of natural gas form the North Sea leave the gas grid open for biogas. Today around 15% of the gas in the natural gas grid is biogas. Some analysis suggest that biogas or synthetic gases can become the main gas in the natural gas grid. It is a very important seasonal storage of energy. It is concluded that the oil and gas reserves – or the lack of them – will have no major changing impacts on the overall Danish economy – and may have a positive impact

on the development of biogas production in Denmark.

Technical: Digitalization: Development of smart solutions. There is a major trend towards digitalization of the Danish society as a whole. The digital solution is across cutting across all economic sectors, and its role in the energy transition is going to be important. It is though difficult to determine the real benefit of the digitalization – although no one will question its importance. Digitalization will allow end users much more information on its energy consumption and end users will eventually have tools and solutions, which will allow consumers to take decision based on real- time information of the energy supply. Whether consumers have the desire to do that is still questioned, but there doesn't seem to be anything, which argues that this is not technically possible in the near future. The mega trend is a continuous development of digital solutions to help reduce energy consumption or encourage energy consumption when the power is produced on renewable energy. The new ICT solutions are the tools for the new stakeholders in the energy sector.

Technical: Urbanization: Urbanization typically creates denser cities and creates a demand for building new (more efficient) buildings. It increases the financial benefit of using district heating or district cooling. Therefore urbanization is an important part of maintaining investments in the cities and often a driver for "smart cities". Urbanization may increase the overall air pollution – unless the share of car-travel is reduced (with public transport and cycling). It is therefore important that the urbanization process occurs together with integrated energy planning strategies. Urbanization has a general densification impact and generally supports a transition to a cleaner and smart energy sector. It is actually necessary that a proactive stance is taken in the energy area in the urbanization process because investments otherwise are decided without considering energy efficiency and sustainability.

Technical: Production of RE technologies: Denmark has been a major player in development of wind turbines. The Danish "love" for wind turbines has meant that specific policies have been implemented to support its penetration of the Danish energy sector. Danish companies have maintained its leading technical position for many years and although there are now major other wind turbine companies around the world, the Danish wind turbine companies are still major players internationally. Regarding solar PV technologies, Denmark plays a very little role. Regarding combustion technologies such as biomass combustion and gasification technologies there has also been developments in Denmark, but without a similar impact on the energy sector as for wind turbines. Regarding Waste-to-Energy plants, waste incineration plants, Danish companies has had success and installed many plants in Denmark as well as internationally. The combustion of waste in Combined Heat and Power plants is major player in the Danish energy sector, and from an energy production point of view plays a significant role due to its CHP capabilities, providing district heating networks with hot water in many cities. From a trend point of view the technical development has had a continues efficiency improvement, which has driven prices down, making them more and more competitive to fossil fuel system. In other words the RE technologies are becoming more and more independent on subsidies for its employment in the energy sector.

Technical: Production of energy efficient technologies: The development of efficient end use technologies has also benefitted from the last decades of long term energy planning towards a carbon free energy sector. This can been seen in development of pumps, motors, meters, windows. The Danish companies in these areas have been able to take advantage of the situation and become major players also at the international lever. The continued improvement of efficiency has also reduced end use consumption and made the more energy efficient appliances cost competitive. The companies play an active role in the green transition process in Denmark.

Technical (electrification): Electricity transmission grid: The electrification process can have a very serious impact on the Danish grid. A large part of the Danish transmission grid is old and is due for replacement. Therefore, the electrification process can help the change to a newer and more modern grid. The electrification process has a high risk of putting real stress on the national electricity grid. If the electrification process occur without smart solutions or upgrade of the grid it can have significant impact on the reliability of current operation of transmission grid. The electrification process is

necessary to exploit the increasing production of RE electricity from wind and solar. Difficult to see the transition coming from other than wind and solar power. It means there is no way around either developing and/or installing smart solutions or upgrade the grid. It is also likely that the combined effort of electrification and digitalization will help decentralizing the energy sector, enabling new technologies and new stakeholders to enter the market.

Technical (electrification): District heating: National district heating networks: The Danish district heating networks covers not only the biggest cities but also many small cities. In Copenhagen, where the connection of DH is highest, the connections rate at 98%. In total 65% of Danish residential households are connected to district heating. Heating represents 40% of the Danish energy consumption. There is therefore a very high potential for using electricity in the heating sector with the use of heat pumps, specifically large scale heat pumps in the district heating sector. The technology is though not readily available. So there still has to be invested in R&D in this area. Therefore it is also not yet clear how big the potential will be from an economic point of view. There are already specific project focusing on developing the technology.

Technical (digitalization): Buildings: Across Denmark new buildings are build every year, typically at 1% increase per year. The new buildings follows building codes, which over the last decades has become increasing strict with regard to energy efficiency. However, the majority of housing stock in Denmark is still build either before building codes were introduced or were built before the first oil crises when the focus on energy efficient buildings starting to emerge. From a digitalization point of view, here is a large potential in automatic operation of heating and cooling systems in buildings. These are typically integrated in new building, but due to its complexity, there is still big room for improvement. With regard to the old buildings, it is more difficult to do energy efficiency project, but they have a big flexibility potential.

Technical (electrification): Transportation: Electrification of both private and public transport (buses and trains) is still in development. Electric vehicles are for all transportation forms superior with regard to emission of air pollutants. Very difficult to see any alternative to electricity in the transportation sector. The electrification of the transportation sector will have a major impact on the national electricity grid. Without smart solutions the demand on the grid may double, asking for a massive increase in transmission capacity. Fortunately, smart solutions can soften the impact. The electrification of the transportation sector is likely to have to have its own focus, its own national strategy focus to facilitate the transition. Encourage use of public transportation and cycling.

Technical: Data centres; In recent years a number of data centres have been built in Denmark. It is the big players such as Apple, Facebook, Google which have shown significant interest in the Denmark. One of the reasons for their interest has been a green energy sector, a reliable electricity grid and the possibility that the heat recovered when the CPUs are cooled can be used as hot water in the district heating networks. If the companies, which have shown interest are also implementing, it will increase the Danish electricity consumption with 20%. Therefore, it can a significant impact on the Danish energy sector. Whether they will produce their own power, by establishing their own wind turbine parks is still not clear.

Environment: Climate change. Denmark are exposed to climate changes like any other country in the world. Although impacts are different among countries. Denmark has already been suffering 1.7 DC increase in average temperature. Denmark has a very long coast line and there are many cities which will be directly exposed to rising sea levels. Flooding of houses therefore occurs regularly and some areas are more exposed than others. Whether the average Dane thinks the increase numbers of floodings are caused by climate change is difficult to say. It is likely that it is being understood. The adaptation cost for Denmark for the sea level rise is going to be enormous and it is still been debated whether the houseowners, the municipalities or the government should be paying. It is therefore certain that the concrete flooding risk but also the overall findings of IPCC regarding overall global climate change is having an impact on the population view on climate change and hence long term energy and climate policies.

Social: Demographics. The Danish population is still increasing. As many people are born as a readying, but there is a continuous surplus of people moving to Denmark compared to the number of people leaving Denmark. This pattern is likely to be sustainable A diminishing population would be putting pressure on many sectors of the economy and may eventually make an economy shrink. Denmark doesn't seem likely to have a diminishing population as other European countries do. The continuous aging of the Danish population does not appear to have an impact on development in the energy sector.

V. DISCUSSION

In the previous section the development in the Danish energy sector over the last decades were presented and some mainly technical megatrends were analyzed. Understanding the Danish energy sector helps to understand the environment in which the political decisions are taken. The question is whether the initiatives in the new energy agreement is aligned with the megatrends – local as well as global. And are the initiatives aligned with the long a long term vision of a transition of the energy sector?

I will only focus on four topics in this discussion, which are also basis for my conclusion. The political decision to digitalize the Danish sector, the electricity sector as well as the heating sector, appear to be the right thing to do. It ambitious, because the energy sector stakeholders may not be ready yet. However, the ambitions is supported by global

Table II: Pros and cons of megatrends in the Danish energy sector.

	Impacts which stimulate 100% VRE action in Denmark	Impact which does not stimulate 100% VRE action in Denmark	Overall Evaluation
Economy: The Danish economy (Local)	Denmark is a rich country. Follows the pattern of northern European countries with Germany as the main trading partner. In particular the Danes have invested a large sum of money in their pension funds.	There don't appear to be a thread to the performance of the Danish economy	No threads immediate Denmark can afford to invest in the future. The large pension funds have declared willingness to invest in the transition of the energy sector. STRONG
Economy: Shift of economic power towards Asia (Global)	The shift of economic power towards Asia is due to development of the Asian economies. Some Countries do install RE technologies and both Danish VRE and EE technologies are demanded	Some argue that the growing economies in Asia is the main concern regarding increasing emissions of CO2. The point of view swings with change in sitting government	It appears that Denmark is not holding back on investments in the energy sector due to the shift of economic power to Asia. Contrary there is quite a focus on exporting Danish success stories. NOT strong
Economy: Oil and gas reserves in the North Sea (Local)	Decline output over the last decade. Natural gas can be replaced by biogas in the national natural gas network. North Sea liquid fuels are sold at international prices in DK.	Although the exploitation of oil and gas in the North Sea has had significant support from the government, the support will also diminish with diminishing output.	The previous investments in the North Sea may change to the RE sector. NOT strong
Technical: Digitalization	The aim of increasing digitalization of the Danish society also has means a requirement of	The digitalization will cause distortion in the old energy sector where people who have been	NOT strong because it is difficult to implement in current energy sector setup. If the change can be

	digitalization of the energy sector. Supports development and implementation of sophisticated IT solutions working real-time	working in the sector for a long time base their decisions on their practical experience – they will have to base decisions on data instead.	implemented – that means strong policies which will support implementation of digital solution then it will be STRONG
Technical: Urbanization	Typically creates denser cities and has a demand for building new and more efficient buildings. It increases the financial benefit of using district heating or district cooling. Encourage use of public transportation and cycling	May increase the overall air pollution – unless the share of car-travel is reduced (with public transport and cycling). Important that urbanization occurs together with integrated energy planning strategies	Generally supports a transition to a cleaner and smart energy sector. It is actually necessary that a proactive stance is taken in the energy area in the urbanization process. NOT strong
Technical: Production of RE technologies (Local)	Danish companies have maintained its leading technical position in building wind turbines for many years and although there are now major other companies around the world.	There don't appear to be any arguments against the transition from Danish companies producing RE technologies in Denmark	A continues investment in the green transition will support many different technologies and therefore many local manufacturing companies. STRONG
Technical: Production of energy efficient technologies (Local)	Danish companies have been able to take advantage of the situation and become major players, also at the international level. Examples are pumps, motors, meters and windows with continuous EE improvements	There doesn't appear to be any arguments against the transition from Danish companies producing RE technologies in Denmark.	A continues investment in the green transition of the Danish energy sector will support many different technologies and therefore many local manufacturing companies. STRONG
Technical (electrification): Electricity transmission grid (Local)	A large part of the Danish is old and is due for replacement, which means massive investments. Therefore, the electrification process can help the change to a newer and more modern grid, but requires an open mind from current operators.	The electrification process has a high risk of putting real stress on the national electricity grid. If the electrification process occur without smart solutions or upgrade of grid it can have significant impact on the reliability of current operation of transmission grid	The electrification process is necessary to exploit the increasing production of RE electricity from wind and solar. There is no way around either developing and/or installing smart solutions or upgrade the grid. STRONG
Technical (electrification): Heating (Local)	Heating represents 40% of the Danish energy consumption. If electricity can be used in the heating sector there will be a very big potential for using electricity with the use of heat pumps, specifically	The technology is though not readily available. There still has to be invested in R&D in this area. It is therefore also not yet clear how big the potential is from an economic point of view.	The potential is big from a technical point of view but still uncertain from an economic point of view. But is well aligned with technology trends and energy policies. STRONG

	large scale heat pumps in the district heating sector.	There are already specific project focusing on developing the technology	
Technical (digitalization): Buildings (Local)	Across Denmark new buildings are build every year, typically at 1% increase per year. The new buildings follow building codes, which over the last decades has become increasingly strict with regard to energy efficiency. People are very positive towards housing renovations	However, the majority of housing stock in Denmark is still build either before building codes were introduced or before the first oil crises when the focus on energy efficient buildings starting to emerge.	Investments in saving project for the building stock had a very little role in the new energy agreement 2020-2030. It is unlucky because despite the difficulties in a achieving the desired CO2 reduction there is still a huge potential and it is well received by the population STRONG
Technical (electrification): Transportation (Global and Local)	Electrification of both private and public transport (buses and trains) is still in development. Electric vehicles are for all transportation forms superior with regard to exposure to air pollution. Very difficult to see any alternative to electricity in the transportation sector.	The electrification of the transportation sector will have a major impact on the national electricity grid. Without smart solutions the demand on the grid may double, asking for a massive increase in transmission capacity. Fortunately smart solutions can soften the impact	The electrification of the transportation sector is likely to have to have its own focus, its own national strategy focus to facilitate the transition. STRONG
Technical: Data centres (Local)	In recent years a number of data centres have been build in Denmark and more are on the way. With a potential 20% increase in electricity consumption it can consume a lot of surplus wind power	It is uncertain how the data centres will be integrated into the Danish energy sector. They may be connected to district heating, they may produce their own power but it is not certain	If the data centres will be buying power in Denmark then a 20% increase in consumption will require 20% higher production. Impact STRONG but UNCERTAIN
Environmental: Climate Change (Local)	The risk of flooding and sea level rising is a tread to many homes in coastal cities in Denmark.	Despite flooding occurrences at regular basis there is still some reluctance in the system to take action. This may be due to lack of clarification about who should pay, home owners, municipalities or the government	The thread of climate change cannot go away by itself – the risk is having an impact on local and national energy and climate policies. But what to do is not decided. STRONG
Environmental: Climate Change (Global)	The findings of IPCC of overall global climate change is also having an impact on long term energy and climate policies	The lack for commitment from other countries does sometimes hold the Danish government back. It depends on the parties in the government.	Although Denmark cannot make the thread of climate change go away by ourselves – the global risk is having an impact on national and local energy and climate policies.

Demographics (Local)	The trend does not have a strong impact on Danish energy policy	The trend does not have a strong impact on Danish energy policy	The trend does not have a strong impact on Danish energy policy NOT strong

megatrends on IT. IT has come from almost nothing a decade ago, but appear very promising. In many ways the benefits of specific IT solutions still need to be proven, but its general support for digitalization throughout society means the energy sector has be part of that. By including the energy sector in the national digitalization strategy, the consumers will see the energy sector strongly aligned with people's daily life where more and more gadgets and apps are available. There are barriers within the sector, which needs to be overcome, but the megatrends is so strong that it is very likely to happen.

The second topic is electrification. The main VRE we have in Denmark, wind and solar, are working very well in the electricity sector. The sun can also be used for thermal energy – and it will be, but it is also important for the power sector. There is a strong focus on expanding wind and solar power in the new Energy Agreement. We will therefore have wind and solar power enough – enough electricity on VRE. The question is whether we can use it all? In the current setup we cannot use it and we end up exporting the surplus power to Norway and Sweden – and even more so with 2400MW of new off shore wind power in the new Energy Agreement. However, electrification has a strong link to the heating and transportation sector – and this is going to be important. There is a very big potential for electricity in the heating and transportation sectors will I will touch in the following.

The third topic is heating. A major part of energy consumption in Denmark is used for heating. With half provided with district heating the focus on fuel shifting and making a 100% RE heating sector is obvious. The strong link between electricity sector and heating is the big potential to provide the necessary heat from heat pumps using electricity. This can be large scale heat pumps for the district heating. However, individual heat pumps can also be used in the residential sector outside the district heating networks. Furthermore, the heating sector can offer flexibility to the power sector. It makes so much more sense to use the surplus of electricity for heating than exporting the power to Norway and Sweden. Fortunately, there is also a strong desire to expand district heating networks in other countries, which makes the electrification and digitalization of the district heating system an export opportunity for many Danish companies.

The fourth topic is transportation. The transportation sector is probably the most important area to where the electricity sector can expand. We will see a fast transition to electric cars in Denmark in the next two decades. It is difficult to doubt that. The question is how fast the cars will come in and how they will be integrated with the power sector. If we are going to have three million electric cars in Denmark in two decades, we will also have three million electric batteries, which can be used as part of the power sector. It is a very likely scenario that all the small car batteries are going to be an important part for the power sector. Probably integrated with solar PV systems, where the batteries will be re-charged during the day. Both the electric cars and solar PV are technologies, which will become mainstream in the next two decades. Solar PV systems will be integrated in new houses. The Danish electricity sector has to see this as a very likely scenario for the future – so when the power grid is going to rebuild in the near future this has to be part of the re-thinking. The integration will also deliver on what people want, clean air, comfort, connectedness, and convenient mobility.

CONCLUSION

The paper has described and evaluated the Danish energy sector policies towards achieving a concrete target of 55% VRE in energy sector and newly defined target of 70% VRE by a new government. Denmark has a very high penetration of RE compared with its peers and in particular countries which use VRE. At a phase four to five state of the Danish VRE integration, the Danish energy sector is already faced with longer periods of more than 100% VRE in the power sector. Installing more wind turbines is therefore not going to be the solution for Denmark right now. The strategy has to be much more sophisticated and encourage development of more sophisticated energy services, which can provide the VRE output as energy services inside the Danish boarders. We don't need to do more for the situation when the wind is blowing. To make maximum use of the wind and sun we have today we have to focus on how we can use flexibility and many types of storage solutions to

expand the power form wind to the time when the wind is not blowing.

The recent long term goal has been to be independent of fossil fuels in 2050. The Danish government appears to be working with many of these mega trends towards a transition to an energy sector 100% based on renewable energy resources. The combined effect of digitalization and electrification of the heating and transportation sectors will stress the current transmission grid unless the use of electricity in the heating and transportation sectors are used in a smart way. This integration should have the center focus in development in the Danish energy sector in the coming decades. There is so much technical development happening in these areas that it is very difficult to see that this will not happen. It will also deliver on what people want, clean air, comfort, connectedness, and convenient mobility. Denmark does not have the advantage of large scale hydropower so relies on VREs, but this analysis does support the vision that we can be 100% independent of fossil fuels in 2050 – if the right decisions are taken.

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